

**Multitasking and Vocational Functioning in Multiple Sclerosis:
A Performance Based Assessment**

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Dedications

This dissertation is dedicated to all individuals diagnosed with MS. Keep S'myelin!

"Can't and quit are words I don't want to have anything to do with. I know that when it's toughest, I'm on the edge of a breakthrough, and because I know that, I keep going. There's a point where your brain gives up fighting against you and starts working for you." -Anonymous individual diagnosed with MS

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Abstract

Multitasking and Vocational Functioning in Multiple Sclerosis:
A Performance Based Assessment
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Cognitive dysfunction in Multiple Sclerosis (MS) has been shown to be associated with difficulty maintaining employment. Previous domain-specific approaches to examining the effects of cognitive impairment on employment have not adequately explained the high unemployment rates in MS. A more complex construct that integrates multiple cognitive domains, known as multitasking ability, may be a more useful predictor of vocational functioning among individuals with MS. The current study examined the usefulness of an ecologically-valid performance based measure of multitasking to predict vocational functioning.

This study had two primary aims: 1) to develop and validate a performance based assessment of multitasking ability, termed the Vocational Multitasking Test (VMT), and 2) to evaluate the ability of the VMT to predict vocational outcomes.

To achieve these aims a pilot phase was first conducted with 10 healthy control (HC) participants to develop standardized administration and scoring procedures for the VMT. Next, a total of 18 participants with MS and 20 HC participants were recruited. These participants were administered a short battery of neuropsychological tests, self-report questionnaires of fatigue and depression symptoms, and two measures of multitasking ability.

Analysis of the psychometric properties of the VMT demonstrated good internal consistency, inter-rater reliability, and concurrent validity. Within MS participants, the

VMT was significantly associated with processing speed and mental flexibility; whereas the VMT was only associated with processing speed in HC participants. Compared to the HC group, participants with MS completed fewer action steps of the VMT, made more errors, and engaged in fewer simultaneous task attempts. Performance on the VMT was significantly associated with vocational functioning and in a model predicting vocational group status, VMT performance and fatigue were able to predict group status with 69% accuracy.

The current study provides preliminary validation of the VMT as a performance based measure of multitasking ability. Results can be utilized in vocational rehabilitation efforts to both modify the structure of an individual's work environment and in making recommendations for vocational placement. Future research should continue to explore the usefulness of the VMT to predict vocational functioning and in informing cognitive rehabilitation strategies.

1: Introduction

Multiple Sclerosis (MS) is an autoimmune disorder characterized by demyelination of the central nervous system, which forms lesions throughout the brain and spinal cord. Chronic and degenerative symptoms typically begin to present in persons in their mid-20s, with individuals diagnosed most frequently between the ages of 20 and 45. Prevalence rates of MS in the United States are indicated at 191 per 10,000 (Mayr et al., 2003), and vary depending on gender, ethnicity, genetic predisposition, and geographic location. The range of disability in MS is variable, including physical, cognitive, and psychological effects.

MS is characterized by a variety of disease forms, differing in the progression of neurologic deficits, time course, and objective experience of symptoms (Blumenthal, 2006). Approximately 55% of individuals are diagnosed with the relapsing-remitting disease (RR) subtype (Lublin & Reingold, 1996), presenting with a profile of symptoms with rapid onset, which then remit with partial or complete recovery. By contrast, a progressive disease course is defined by gradual accumulation of neurologic deficits and worsening of clinical symptoms as time progresses. The predominant progressive subtype accounting for 30% of individuals with MS (Lublin & Reingold, 1996) is secondary progressive (SP), characterized by a gradual worsening of symptoms with or without disease exacerbations. A diagnosis of primary progressive (PP) subtype is based on a gradual worsening of symptoms without discrete disease exacerbations. Many individuals originally diagnosed with RR are later classified as SP as their relapses become relatively more infrequent or absent (Blumenthal, 2006). .

Diagnosis of MS is based on medical history, a neurological examination, cerebral spinal fluid abnormalities, brain and spinal cord MRI abnormalities, and increased latency of evoked potentials. Clinical presentation of symptoms in MS varies widely between individuals; however there are clusters of symptoms that typically manifest in this population. Somatosensory, motor, and visual disturbances are often the first symptoms reported by individuals (Herndon, 2000). Additionally, mood and affective changes occur in individuals with MS; lifetime prevalence of major depression ranges from 40 to 60 percent (Aikens, Fischer, Namey, & Rudick, 1997). Cognitive dysfunction is one of the most disabling features of MS, occurring in about 43-65% of MS individuals (Fischer, 1999; Rao, Leo, Bernardin, & Unverzagt, 1991), and resulting in significant impairments in an individual's work and social activity. Cognitive deficits have been shown to be an independent predictor of functional impairment in MS over and above an individual's degree of physical disability (Amato, Ponziani, Siracusa, & Sorbi, 2001; Beatty, Blanco, Wilbanks, Paul, & Hames, 1995), highlighting cognition as an important marker of disease progression and patient quality of life.

The onset of cognitive symptoms is variable in MS. At disease onset 26 to 54% of individuals present with cognitive deficits (Amato, Ponziani, Pracucci, Bracco, Siracusa, & Amaducci, 1995; Zivadinov et al., 2001), a percentage which increases with disease progression (Kujala, Portin, & Ruutiainen, 1997). More recent research has shown that cognitive changes in MS usually are not global, but are circumscribed to key domains of cognitive impairment, including memory, learning, and information processing speed (Fischer, 1999). Deficits in the domains of linguistic ability, visuo-

spatial abilities, and executive functions such as reasoning, problem solving, and planning are also common.

Although about 80% of individuals with MS who have cognitive deficits are relatively mildly affected, even mild levels of cognitive impairment have been shown to impact various aspects of individuals' lives including, activities of daily living (Goverover, Genova, Hillary, & DeLuca, 2007), social functioning (Rao, Leo, Ellington, Nauertz, Bernardin, & Unverzagt, 1991), driving (Schultheis, Garay, Millis, & DeLuca, 2002), and in particular employment (Kornblith, LaRocca, and Baum, 1986; Rao et al., 1991).

1.1 Vocational Functioning in MS

Unemployment following diagnosis of MS is well documented, with rates reported at 50 to 80% within 10 years of diagnosis (Fischer, 1999). The unpredictability and variability of MS symptoms creates significant challenges to career planning and decision making regarding employment status. Employed individuals with MS report a higher quality of life, more effective social supports, and better perceived health as compared to unemployed individuals with MS reporting similar levels of physical disability (Kraft & Catanzaro, 1996). Further, individuals with MS report that employment is associated with increased financial security (Miller & Dishon, 2005), which is important given the increased medical costs associated with disease burden and treatment.

Prior research has shown that a number of demographic and disease characteristics are related to unemployment in MS, including increased age (Beatty, Blanco, Wilbanks, Paul, & Hames, 1996), longer disease duration (Benedict et al., 2005;

Busche, Fisk, Murray, & Metz, 2003), greater physical disability (Kornblith, La Rocca, & Baum, 1996; Julian, Vollmer, Hadjimichael, & Mohr, 2008; Verdier-Tailefer et al., 1995), and depression (Roessler & Rumrill, 1995). In particular, cognitive dysfunction has been shown to be predictive of unemployment in MS (Beatty et al., 1996; Rao, et al., 1991). Many individuals with MS will experience a restriction in vocational functioning due to the physical consequences of the disease, but the subset that also present with cognitive impairment are likely to be disproportionately more affected on the job (Rao et al., 1991).

1.1.1 Cognitive Predictors of Vocational Functioning

The cognitive domains found to be significantly associated with vocational functioning in MS include, working memory, executive functions, processing speed, and attention (Beatty et al., 1995; Benedict et al., 2005). The literature examining the relationship between cognition and employment has been developing over the past 21 years, but contains notable limitations, suggesting that this relationship is not fully understood. Studies are marked by inconsistency in the neuropsychological domains found to be associated with employment status. Reasons for this inconsistency may include confounding factors such as predysfunction employment status, premorbid intellectual functioning, psychiatric disorders, and/or age at which an individual is diagnosed with MS (Sherer et al., 2002). Additionally, only a limited proportion of variance in employment status has been explained by neuropsychological factors. The limitations of taking a domain specific approach to measuring predictors of employment status are acknowledged by Burgess and colleagues (2006), who proposed that neuropsychological tasks are limited in their ability to predict impairments in everyday

“real-world” activities, such as employment, because they do not capture the environmental demands of daily life. Indeed, neuropsychological measures by design limit external factors (e.g., distraction) and task complexity, which contrasts to tasks of real-world functioning that require the ability to prioritize, organize, and structure a course of action in the face of competing alternatives in everyday situations. Thus, measurement of more complex or integrated cognitive performance (i.e., multitasking) may represent a more ecologically valid approach to examining vocational functioning, and provide a better understanding of challenges faced by individuals with MS in the workplace.

1.2 Multitasking Ability

In the current study, multitasking will be operationalized as an individual’s ability to complete multiple discrete tasks within a specific timeframe where switching between tasks is required. Multitasking involves the creation and maintenance of delayed intentions, where the individual determines the appropriate time to return to a task. Often in this context the individual must determine what constitutes adequate performance on a task in the absence of minute-by-minute performance feedback. Unforeseen circumstances also play a role in the context of multitasking, as individuals must maintain sub-goals of each task while addressing interruptions or distractions (Burgess, 2000). Many studies have related the term multitasking to dual-task paradigms where individuals are simultaneously performing multiple tasks or are allocating attention to multiple streams of input (Meyer & Kieras, 1997). In the current study, it is acknowledged that simultaneous performance of tasks can occur, but is not required as

multitasking is defined as the ability to carry out a series of discrete tasks within a specific timeframe.

1.2.1 Theoretical Framework of Multitasking

Research has shown that an isolated set of cognitive and neuroanatomical systems likely support multitasking. Three cognitive constructs have been shown to be associated with multitasking ability: retrospective memory, planning ability, and prospective memory (Burgess et al., 2000). The primary neuroanatomical correlates of these cognitive abilities while an individual is engaging in multitasking are the medial left hemisphere, right dorsolateral frontal region, medial left frontal region, and the left anterior cingulate and surrounding paraventricular regions (Burgess et al., 2000). Implication of the frontal lobes in multitasking processes provides support for examining multitasking deficits in MS due to the relative frequency of frontal lobe lesions in MS (Foong et al., 1997) and the presence of executive functioning deficits in MS related to frontal lesion load (Arnett et al., 1994; Swirsky-Sacchetti, 1992).

1.3 Evidence of Multitasking Deficits in MS

Preliminary support for the examination of multitasking ability in relation to vocational functioning in MS was provided by Morse and colleagues (2013). In this previous study, the Modified Six Elements Test (SET; Shallice & Burgess, 1991) was utilized to measure multitasking ability. The SET was developed as a lab based model of everyday functioning to measure voluntary delayed task switching, and has been shown to be associated with self-reported difficulty with multitasking in everyday life. Performance requires participants to switch between six different tasks within a 10

minute timeframe, and is quantified by the number of tasks attempted, maximum amount of time spent on any one test, and number of rule breaks.

Results of this preliminary study showed that individuals who were either unemployed or had reduced their work hours since being diagnosed demonstrated reduced multitasking ability as compared to employed individuals. Performance on the SET was measured with the standard profile score, as well as two qualitative measures of performance, i.e., overall amount of the SET completed and total number of task switches. Analysis of group differences in SET scores showed that only the overall amount of SET completed was statistically different between 1) unemployed and employed individuals, and 2) individuals who had maintained their work hours and those who had reduced their work hours since diagnosis. In a predictive model of vocational group status both fatigue and multitasking (i.e., overall amount of SET completed) were retained as independent predictors, whereas depression, level of physical disability, and performance on traditional neuropsychological measures were not. The findings of Morse and colleagues (2013) were the first to demonstrate a relationship between multitasking ability and vocational functioning in MS, and provide evidence for the importance of continued study of this relationship to inform predictions of vocational functioning.

Continued study of the relationship between multitasking ability and vocational functioning must address the limitations of this previous study. One limitation was the use of only one test to measure multitasking ability, i.e., the SET. The validity of the SET has been demonstrated in other studies; however these studies were conducted with brain injured populations diagnosed with dysexecutive syndrome. Given that individuals

with MS often demonstrate more subtle cognitive impairment, perhaps a more challenging task is needed to measure multitasking ability in this clinical population. Additionally, the rules of the SET are structured so that ideal performance involves spending approximately one-sixth of the allotted time on each subtask, thus participants are not likely to complete any one subtask. While this assesses one's ability to plan their time correctly, it does not assess an individual's ability to work efficiently toward completing a goal, to set priorities, or to perform multiple tasks simultaneously, which are skills often required in the workplace. Sadek and van Gorp (2009) define this limitation of the SET as a problem of verisimilitude (Franzen & Wilhem, 1996), referring to the level of similarity between an assessment measure and the real-world behaviors it purports to measure. Improving the ecological validity of methods used to assess multitasking would likely provide better prediction of performance in the challenging and complex environmental demands of the workplace. The current study aims to address these limitations and extend previous findings of Morse and colleagues (2013), by developing a performance based assessment of multitasking ability to predict vocational functioning in MS.

1.4 Performance Based Assessment of Multitasking

One prior study in the literature has developed a performance based measure of multitasking ability in response to the limitations of the SET. Scott et al. (2011) examined the relationship between multitasking ability in HIV-1 infected persons and everyday functioning, by developing a novel multitasking test modified from the SET to include component tasks with face validity for instrumental activities of daily living (IADLs). The multitasking measure was divided into four separate tasks, with

participants required to complete as much of each part as possible in a 12 minute time period. The tasks included cooking, advanced finance management, medication management, and telephone communication. Participants received points for the number of steps in the task they were able to complete, and qualitative variables were examined such as number of task switches, simultaneous task attempts, repeated task steps, performance of irrelevant task steps, and performing task steps in the incorrect order. This novel multitasking measure was tested for predictive and ecological validity in HIV-infected individuals demonstrating neuropsychological impairment. Results showed that multitasking deficits were uniquely predictive of IADL dependence beyond effects of depression and global cognitive impairment, with excellent sensitivity (86%) and modest specificity (57%). Further, a nominal logistic regression model that attempted to predict employment status from overall score on the multitasking measure was significant. The evidence based theoretical framework used by Scott et al. (2011) provides an excellent model for a performance based assessment of multitasking ability, and supports the utility of developing a vocationally oriented analogue to predict vocational functioning in MS.

1.5 Current Study

Cognitive dysfunction is one of most disabling features of MS and has been shown to be associated with difficulty maintaining employment in MS. A review of the literature demonstrates that previous domain-specific approaches to examining the effects of cognitive impairment on employment have not adequately explained high unemployment rates in MS. Performance on a more complex task that integrates multiple cognitive domains, known as multitasking ability, may be a more useful predictor of vocational functioning among individuals with MS. Morse and colleagues (2013)

addressed the limitations of prior studies by initiating a novel investigation of multitasking in MS using the SET, and examining the relationship between multitasking ability and vocational functioning. This study demonstrated a relationship between multitasking ability, defined by total amount of the SET completed, and vocational functioning, lending support for further characterization of multitasking ability in MS. However, a more challenging measure of multitasking ability that includes face valid tasks and provides a qualitative analysis of multitasking performance may improve vocational outcome predictions. Additionally, a more detailed assessment of multitasking ability in relation to vocational functioning can aid clinicians in identifying which specific aspects of multitasking ability are related to reduced capacity to work and how rehabilitation efforts can target these areas.

Much of the research examining vocational outcomes in MS has grouped individuals as either employed or unemployed. In persons living with MS, the most common vocational pattern is to move from an original position to one that places fewer demands on the individual, and then subsequently to transition into retirement, unemployment, or disability (Jackson, Quall, & Reeves, 1991). Some researchers like Smith and Arnett (2005) have demonstrated the usefulness in identifying variables that distinguish between individuals who have maintained and reduced their work hours since diagnosis. Morse and colleagues (2013) grouped individuals depending on whether they had maintained or decreased their work hours since diagnosis. This approach was shown to be a sensitive method for detection of clinical and functional differences between groups. The current study aims to inform rehabilitation efforts targeting maintenance of

employment status for individuals with MS. Consequently, only individuals with MS who are employed will be included in the current study.

The current study will extend findings from Morse and colleagues (2013) by introducing a novel performance based measure of multitasking ability and by utilizing vocational outcome measures beyond traditional classifications of unemployed and employed. The outcome of employment was chosen as the focus of this study due to the high prevalence of unemployment following diagnosis of MS, and the demonstrated associations between employment and higher quality of life, more effective social supports, and better perceived health (Kraft & Catanzaro, 1996). To achieve this, the current study investigated two primary study aims. First, a novel performance based measure of multitasking, termed the Vocational Multitasking Test (VMT) was developed and validated. Second, the ecological validity of the VMT was evaluated by examining relationships between performance on the VMT and vocational outcomes.

The specific aims for this proposal are:

Aim 1. To develop and validate the Vocational Multitasking Test (VMT), a performance based assessment of multitasking ability, to predict vocational functioning.

Morse and colleagues (2013) demonstrated that multitasking ability, defined by performance on the SET, was significantly associated with vocational functioning. As a next step, developing a measure of multitasking that better captures the complex demands of the workplace may provide a more ecologically valid assessment of multitasking ability. Additionally, this approach may better inform rehabilitation efforts.

Consistent with this objective, the current study developed a performance based measure of multitasking ability modeled after the task developed by Scott and colleagues (2011). This measure, termed the Vocational Multitasking Test (VMT), incorporates component tasks measuring activities and abilities shown to be relevant to performance at work. Additionally, a standardized scoring procedure for the VMT that is consistent with methods developed by Scott and colleagues (2011) was developed to define performance on the VMT. Given the novel nature of the VMT, it was first piloted on 10 healthy control individuals to develop standardized administration procedures. Following the pilot phase, the final manualized VMT was administered to 38 participants. The internal consistency of scores on the VMT was examined using Cronbach's coefficient Alpha, and Cohen's Kappa was used as a measure of inter-rater reliability. Additionally, concurrent validity of the VMT was evaluated through comparison of performance on the VMT and SET, given that the SET has previously been established as a measure of multitasking ability in the literature.

Inconsistent relationships have been demonstrated between multitasking ability and performance on traditional neuropsychological tests. Some studies have demonstrated that multitasking ability is independent of performance on neuropsychological measures (Burgess et al., 2000; Scott et al., 2011). In a prior study, Morse and colleagues (2013) found that the overall amount of the SET completed was associated with performance on tests of information processing speed and working memory. In the current study, the relationship between performance on traditional neuropsychological measures and the VMT in individuals diagnosed with MS and HC was analyzed. Finally, in the previous study individuals with MS demonstrated

impairment in multitasking ability (Morse et al., 2013), which was the first demonstration of decreased multitasking ability in MS. As a follow-up to this finding, performance on the VMT will be compared between individuals with MS and healthy controls.

Aim 2. To examine the validity of the VMT to predict vocational outcomes in MS.

Morse and colleagues (2013) found that individuals who were unemployed or had reduced their work hours since diagnosis demonstrated more impairment on a measure of multitasking than individuals who were employed or had maintained their work hours. The current study will extend these findings by defining multitasking ability employing a performance based assessment to predict vocational functioning. Although previous studies have examined vocational outcomes, individuals with MS have traditionally only been categorized as employed or unemployed. The current study will examine vocational outcomes by calculating ratios of time spent working since diagnosis, measuring self-reported productivity and absenteeism at work, and comparing individuals who have reduced their work hours since MS diagnosis and those who have maintained their work hours. Examining the relationships between vocational functioning and VMT performance will establish the ecological validity of the VMT. Lastly, incremental validity of the VMT was examined by assessing whether the VMT was able to explain additional variance in vocational outcomes beyond the variance explained by traditional neuropsychological measures.

2: Methods

2.1 Study Overview

This study aimed to 1) develop a performance based assessment measure of multitasking ability and 2) validate the measure as predictive of vocational functioning in MS. To achieve this, the first phase of the study was to pilot the VMT in order to make modifications that culminated into the final standardized VMT administration and scoring procedures. The second phase of the study examined the psychometric properties of the VMT and its associations with vocational functioning. The second phase of the study employed a cross-sectional design with a total of 18 participants diagnosed with MS and 20 healthy control participants. Participants in the study were recruited from the greater Philadelphia area community. All participants were seen for one three hour testing session, in which they were administered a cognitive battery, the Six Elements Test (SET), the Vocational Multitasking Test (VMT), and self-report questionnaires examining fatigue, depression, and vocational functioning. Order of the VMT and neuropsychological measures was counter-balanced across participants. The primary goals of the current study were to 1) develop and validate the VMT as a performance based measure of multitasking ability, and 2) examine the validity of the VMT to predict vocational outcomes. Independent *t*-tests, Mann-Whitney, correlational, and regression analyses were used to investigate and achieve these goals.

2.2 Participants

Forty-eight participants recruited from February 2013 to April 2014 were included in the present sample. Ten of the participants were healthy control participants and were only included in the VMT piloting phase. The remaining 38 participants included individuals with MS ($n = 18$) that met the Posner diagnostic criteria (1983), and

healthy control participants ($n = 20$) that were age, gender, and ethnicity matched to the MS sample. MS participants were not excluded based on disease-type. Participants met the following inclusion criteria: 1) diagnosis with MS for at least one year, 2) between 21 and 60 years of age, 3) stable regimen of medications within past 30 days, and 3) currently employed, defined as working a minimum of 20 hours per week for a period greater than one week (Machamer, Temkin, Fraser, Doctor, & Dikmen, 2005).

Additionally, the following were exclusion criteria:

- Neurological History: Individuals with a significant neurological history other than MS, including moderate to severe head injury, stroke, and seizure were excluded from the study.
- Psychiatric and substance abuse history: Individuals with a significant psychiatric history, defined by diagnosis and/or treatment of schizophrenia, bipolar disorder, or psychosis, or persons undergoing medical treatment for substance abuse, or actively using substances at the time of testing were excluded.
- MS disease burden and treatment: MS participants had not experienced an exacerbation of symptoms within 30 days prior to testing. All participants prescribed medications shown to adversely affect cognition such as steroids, benzodiazepines, neuroleptics, opioids, anti-convulsants, and narcotic analgesics were excluded.

2.3 Power Analysis

Power analysis was conducted according to Cohen's standards (1988; 1992). In Aim 1, to examine relationships of the VMT with the SET and traditional neuropsychological measures using bivariate correlational analyses, 25 participants were

needed to achieve .95 power assuming a large effect size with a significance criterion of .05 (Cohen, 1992). Additionally in Aim 1, to examine differences in VMT performance between MS and HC groups, 40 participants were needed in each group to achieve .80 power with an alpha level of .05 assuming a medium effect size. In this analysis, the actual achieved sample size yielded power of .42 to obtain a medium effect size. In Aim 2, correlation analyses with three independent variables, alpha level of .05, sample size of 18 participants yielded power of .69 to obtain small medium effect size. Using logistic regression analysis with three predictor variables, a sample size of 18 participants and alpha level of .05 yielded power of .40 to obtain a medium effect size.

2.4 Assessment Measures

All study participants were administered a battery of tests and questionnaires to examine aspects of 1) multitasking ability, 2) traditional neuropsychological performance, 3) vocational functioning, 4) motor function, and 5) psychosocial functioning.

2.4.1 Multitasking Ability

Multitasking performance was assessed with the Six Elements Test (SET) and the Vocational Multitasking Test (VMT).

2.4.1.1 Modified Six Elements Test (SET; Shallice & Burgess, 1991). The SET is a 10 minute task where participants are instructed to complete three tasks (dictation, picture naming, and arithmetic). Each task is divided into two components, A and B. The participant is free to structure their performance on tasks while following two rules. Participants must attempt each of the six task components, while not engaging in sections A and B of the same test consecutively. The test is designed so that it would be

impossible to finish all three tasks within the 10 minute time limit. A rater observes performance and scores the number of tasks attempted, maximum time spent on any one test, and the number of rule-breaks committed by the participant according to the scoring method developed by Burgess and colleagues (1991). Total Overall SET score, which takes into account the total number of items a participant accurately completes on the SET, was used as the dependent measure. Use of the Total Overall SET score is supported by findings from a previous study demonstrating that this variable showed the greatest association with vocational functioning (Morse, et al., 2013).

2.4.1.2 Vocational Multitasking Test (VMT). The VMT requires participants to complete as much of four separate tasks as possible within a 12 minute time limit. Task parameters of the VMT were modified from the SET and the performance based task developed by Scott et al. (2011). Components of the four separate tasks were developed as an integration of data reported in the Occupational Information Network (O*NET; U.S. Department of Labor, 2006). The O*NET is a report generated by expert panels that identifies cognitive abilities considered to be “worker characteristics” and general work activities individuals may engage in at work. See Appendix A and B for relevant worker abilities and activities included in the O*NET report. Table 1 summarizes the modifications from the original tasks utilized by Scott and colleagues (2011) and relevant O*NET abilities and activities for each component task of the VMT. Component tasks include: 1) Office Supplies (purchasing mock office supplies online); 2) Advanced Finances (paying bills and balancing a checkbook); 3) Time Card (comprehending a verbal description, organizing information, and then entering it into a spreadsheet); and 4)

Telephone Communication (making three phone calls and leaving specified voicemails).

Table 2 summarizes each of the four component tasks.

All instructions for the VMT were provided orally to the participant, which are transcribed on pages 5-7 of the VMT manual. While the examiner provided task instructions orally, the participant viewed a written summary of the instructions, which can be found on pages 21-23 of the VMT manual. The written summary of the instructions remained visible to the participant throughout the entire test to limit demands on memory for the instructions. Following explanation of the four tasks to participants, the examiner then explained the overall rules and goals of the VMT.

In the VMT, the Office Supplies and Advanced Finances task are assigned importance, so that if a participant completes them they receive bonus points. These tasks were chosen as priorities because they are the most cognitively demanding of the four tasks and a task switch is required before initiating the Advanced Finances task. Two required task switches are built into the VMT: 1) participants must call the credit card company before beginning the Advanced Finances task, and 2) participants must call their manager to report the number of hours they calculated working during the Time Sheet task. In summary, the participant was instructed to attempt at least part of each of the four tasks, to appropriately switch between particular tasks when indicated, and to designate two particular tasks as a priority.

Prior to administration of the VMT, participants completed a questionnaire assessing familiarity and frequency of Internet use, termed the “Internet Use Questionnaire” (pages 43-44 of VMT manual). Upon completion of the VMT, participants were administered a questionnaire assessing their perception of task

difficulty, clarity of task instructions, perception of how they performed on the task, and any comments or suggestions they had for the examiner about the VMT. Feedback was collected from participants due to the novelty of the VMT. This questionnaire was termed the “Post VMT Questionnaire” (page 45 of VMT manual).

Scoring methodology for the VMT was adapted from Scott and colleagues (2011). Refer to pages 25-40 in the manual for specific scoring sheets and guidelines. For each of the four tasks, one point was awarded for correct execution of each step of the task. Total number of points was summed to calculate the total amount of the task completed, *VMT.Overall.Score*. To characterize each participant’s performance, the following additional error and qualitative variables were examined:

Error Variables:

1. *VMT.Repetition Errors*- Repeating a specified step more than instructed to.
2. *VMT.Intrusion Errors*- Performing or adding an irrelevant step to the task
3. *VMT.Omission Errors*- Leaving out task steps or not completing a specified step
4. *VMT.Sequencing Errors*- Performing a series of task steps in the wrong order
5. *VMT.Other Errors*- Errors not classified above
6. *VMT.Total Errors*- Total number of errors for 1-5.

Qualitative Variables:

1. *VMT.Plan.Time*- Number of seconds participant utilizes to plan their performance before initiating the task during the provided optional minute of planning time; ranges from 0-60 seconds.

2. *VMT.Tasks.Attempted*- Total number of tasks the participant engages in, with engagement defined as completing a minimum of one task step; ranges from 0-4 tasks.

3. *VMT.Simultaneous*- Performing any second task while a first task is ongoing (e.g., talking on the phone while working on another task). Engaging in a task is defined as completing at least one task step in the associated task.

4. *VMT.Switch*- Number of between task switches. A task switch occurs when a participant momentarily discontinues actively working on one task and begins work on a second task. The participant does not need to complete any of the task steps of the second task to meet criteria for a task switch (e.g., directing visual gaze to Time Sheet stimuli, but not completing any of the Time Sheet task steps).

5. *VMT.Switch.Attempt*- Number of between task switches where a participant discontinues actively working on one task and begins working on a second task and completes at least one step of the second task.

6. *VMT.Total.Changes*- Sum of “task switches” and “task switches plus attempts”.

The lead author and two research assistants administered and scored the VMT in accordance with standardized procedures. Research assistants were trained using “mock” participants to learn the appropriate administration and scoring procedures. During the study, in order to increase the reliability of scoring, all participants were videotaped while performing the VMT. Scoring occurred in two phases: 1) “live” scoring of participant’s performance during the VMT administration, and 2) follow-up “retrospective” scoring of participant’s performance by viewing the videotape. Any inconsistencies in scores

between the live and retrospective scoring sessions were reviewed and rectified by the lead author.

2.4.2 Cognition

Cognitive domains shown to be associated with multitasking performance in past studies were examined using standardized and research-based measures recommended by the Minimal Assessment of Cognitive Function in MS (MACFIMS; Benedict et al., 2002) to assess areas of general intellectual functioning, learning and memory, information processing, and problem solving. Due to concerns with low statistical power, an overall cognitive deficit score was calculated by converting raw scores on neuropsychological measures to demographically adjusted T scores, and then assigning a degree of deficit on a scale of 0 (no deficit) to 5 (severe deficit) in the following manner: T scores ≥ 40 (Deficit score = 0), T scores 39-35 (Deficit score = 1), T scores 34-30 (Deficit score = 2), T scores 29-25 (Deficit score = 3), T scores 24-20 (Deficit score = 4), and T score ≤ 19 (Deficit score = 5). A Global Deficit Score (GDS; Carey et al., 2004; Heaton, Miller, Taylor, & Grant, 2007) was then calculated by averaging the deficit scores across all neuropsychological measures to serve as an index for overall level of impairment.

2.4.2.1. Wide Range Achievement Test-III Reading test (WRAT-III; Wilkinson, 1993). Premorbid intellectual ability can influence neuropsychological performance (Lezak, 1995). Additionally, Scott and colleagues (2011) demonstrated that overall intellectual ability was significantly associated with multitasking ability. Premorbid intellectual ability was measured with the Reading test of the WRAT-III. Participants were asked to pronounce 42 words of increasing difficulty. Total number of words named correctly was the dependent measure in this study (WRAT-Total).

2.4.2.2. *Paced Auditory Serial Addition Test (PASAT; Rao, Leo, Ellington et al., 1991).* The PASAT was administered to assess processing speed, working memory, and sustained attention. The PASAT has been shown to be predictive of return to work after head injury (Gronwall & Sampson, 1974), and has been adapted as the cognitive component of the Multiple Sclerosis Functional Component (MSFC) score due to its sensitivity in the MS population (Fischer et al., 1999). This task requires patients to add 61 aurally presented single digits so that each digit is added to the one immediately preceding it. Participants completed an initial trial with an inter-stimulus of 3.0 seconds. Following a short break, the participant completed a trial with a 2.0 second inter-stimulus interval. Dependent variables were the total number correct on each trial (PASAT-2 and PASAT-3), and the total number correct across trials (PASAT-Total).

2.4.2.3. *Oral Symbol Digit Modalities Test (SDMT; Smith, 1982).* Processing speed was assessed using the oral SDMT given the presence of motor disturbances in MS. This measure has demonstrated sensitivity and specificity for information processing difficulties in MS (Parmenter, Weinstock-Guttman, Garg, Munschauer, & Benedict, 2007). The oral version of the SDMT has been normed according to age and education level, and has been shown to have good psychometric across many samples of participants (Smith, 1982). For this task, participants are given a sheet of paper with a set of nine geometric symbols paired with numbers from one to nine. Participants are required to say out loud the number that corresponds to each geometric symbol for a total of 90 symbols. The dependent variable was the total number of correctly matched items in 90 seconds (SDMT-Total).

2.4.2.4. *Digit Span* (DS; Wechsler, 2008). The Digit Span task, a subtest of the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV), is a standardized working memory and sustained attention task. Stimuli in this task consist of number series beginning with a two-number sequence. In the Digits Forward task, participants verbally repeat the number series verbatim and are given increasingly longer digit series upon meeting the performance criterion. Two trials are presented for each digit series length, and the task is discontinued following a failure on both trials. In Digits Backward, the participant must recite the numbers in reverse order, and in Digits Sequencing, participants must recite the numbers in numerical order. The dependent variables were the total number of correct trials across Digits Forward, Digits Backward, and Digits Sequencing (DS-Total).

2.4.2.5. *California Verbal Learning Test-II* (CVLT-II; Delis, Kramer, Kaplan, & Ober, 2000). Impaired recall of previously learned information is the most common cognitive complaint of MS patients (Rao, 1989). Participants were required to learn a 16-item word list over five trials followed by a new 16-word interference list, and then recall of the first list is reassessed. Delayed recall and recognition of the first list were assessed after a 20-minute filled delay. Total number of words recalled on Trials 1-5 (CVLT-II.Total) and on the delayed free recall trial (CVLT-II.Delay) have been shown to be most sensitive to cognitive impairment in MS and were used as dependent measures (Delis, Kramer, Kaplan, & Ober, 1987).

2.4.2.6. *Trail Making Test* (TMT A & B; Reitan, 1979). The TMT will be used as a measure of information processing speed and executive functioning. Part A of the TMT requires participants to recruit processing speed and visuospatial skills to sequence

numbers distributed on a page. Part B of the TMT adds a cognitive flexibility component to the original task. Participants were scored based on how quickly they were able to accurately complete the task. Dependent variables were the total time to complete Part A (TMT-A) and total time to complete Part B (TMT-B).

2.4.3. Vocational Outcomes

Vocational functioning was examined using three methods. The first was to assess whether participants have successfully or unsuccessfully maintained their work hours since diagnosis. This assessment yielded categorization of individuals into two groups: 1) those who have maintained employment (ME), defined as uninterrupted work since diagnosis regardless of the number of jobs held, and 2) those who have failed to maintain employment (FME), defined as periods of unemployment between jobs and/or a reduction in the number of hours worked per week since diagnosis for reasons attributable to MS symptoms. The second method to characterize vocational functioning was calculation of a ratio based on the number of months since diagnosis that participants have worked without reducing their work hours or responsibilities, specifically the Monthly Employment Ratio (MER; Wehman et al., 1993). Score on the MER can range from 0-1, with higher numbers indicating higher engagement in work since MS diagnosis. In a previous study examining vocational outcomes for individuals who had sustained TBI, the MER was shown to be sensitive to differences in neuropsychological performance, pre-injury work stability, and TBI severity (Machamer et al., 2005). The MER is calculated by:

$$\frac{\text{Number of months since diagnosis without change in work status}}{\text{Number of months diagnosed with MS}}$$

The final method to examine vocational functioning was administration of the World Health Organization Health and Performance Questionnaire (Kessler et al., 2003; WHO HPQ). The HPQ asks a number of questions about work absenteeism, i.e., hours missed from work and reduced productivity at work over the past 28 days. Presenteeism is also measured by the HPQ, and assesses the participant's quantity and quality of work on the job over the past 28 days. Each of these constructs is represented by an overall score, which will be used to characterize vocational functioning.

2.4.4. Physical Functioning

Given the physical requirements of the VMT, motor functioning will be measured to account for potential effects on performance independent of impairment in multitasking ability. To measure overall MS-related disability, the Multiple Sclerosis Functional Composite score (MSFC; Fischer, 1999) was calculated. The MSFC is comprised of three functional measures, which target key clinical dimensions of MS: upper extremity functioning (Nine Hole Peg), lower extremity functioning (Timed Walk Test), and cognitive function (PASAT) that can be used to detect change over time in level of disability. Scores on component measures are converted to standard scores and are averaged to form a single MSFC score.

2.4.4.1. Timed Walk Test (TWT; Fisher, 1999). The TWT was used to examine lower extremity functioning. Score is the time it takes a participant to walk 25 feet with usual aids. Two trials were performed and an average time was calculated for each participant. Mean performance time was the dependent measure of lower extremity functioning (TWT).

2.4.4.2. *Nine Hole Peg (9-HPT; Fischer, 1999)*. The 9-HPT was used to examine upper extremity functioning. Specifically, the 9-HPT is a timed walk test that requires the person to put nine pegs into a pegboard in any order and to subsequently remove them as quickly as possible. Two trials were conducted for both the dominant and non-dominant hands, and the average of the two trials for each hand was used as the score. Mean performance time with the dominant hand (9-HPT-Dom) and non-dominant hand (9-HPT-Nondom) served as the dependent measures of upper extremity functioning.

2.4.5. *Self-report Questionnaires*

Cognition and vocational functioning have been shown to be adversely affected by emotionality (Arnett et al., 1999; Goverover et al., 2005) and fatigue (Beatty et al., 1995; Strober & Arnett, 2005). Several questionnaires quantifying the levels of these factors will be administered.

2.4.5.1. *Psychosocial Interview*. The psychosocial interview will include several questions regarding participant demographics, education, and employment history. Participants will be asked directly if they have reduced their hours due to their MS symptoms. Participants who indicate that they have reduced their hours will be asked to specify what symptoms were most responsible for their change in employment status. Employment characteristics prior to diagnosis will be measured, including yearly income at the time of diagnosis and pre-diagnosis work stability, defined as working half time or more in a job held for at least six months (Machamer et al., 2005).

2.4.5.2. *Fatigue Severity Scale (FSS; Krupp et al., 1989)*. The FSS is a 9-item self-report inventory commonly used in individuals with MS to evaluate their subjective

level of fatigue interference over the past week using a 7-point Likert scale. It was developed to differentiate fatigue from clinical depression as they share common clinical features and can lead to misdiagnosis in neurological populations (Strober & Arnett, 2005). In a prior study conducted by this author, the FSS accounted for over half of the variance in employment status (Morse et al., 2013).

2.4.5.3. Chicago Multi-Scale Depression Inventory (CMDI; Nyenhuis et al., 1998). Depression is common in MS and can adversely affect performance on memory and attention based assessments (Arnett et al., 1999). Depressed mood was measured using the Chicago Multiscale Depression Inventory (CMDI; Nyenhuis et al., 1998). The CMDI consists of mood, evaluative, and vegetative subscales. The mood subscale contains 14 items that assess depression without taking into account neurovegetative effects that are often present in persons with MS. Prior work (Arnett et al., 1999; Nyenhuis et al., 1998) recommends that only the non-vegetative scales from the CMDI be used to avoid potential misidentification of MS symptoms as vegetative depression symptoms. All three subscales were administered in the current study and two scores from the CMDI were calculated, 1) total CMDI score including the vegetative subscale and 2) CMDI Mood score. On the CMDI, participants were asked to rate the extent to which each item describes the way they have been feeling over the past week, including the present day, on a five-point scale.

2.5 Procedures

For the pilot phase, participants were recruited from the Advanced Neurotechnologies Lab (ANT) and staff in the Department of Psychology at Drexel University. Pilot participants completed only the VMT during their session and were not

compensated for their participation. Data collected during the pilot phase was not used in the final study analyses and participants were not compensated. Following the pilot phase, recruitment procedures for the main study sample included hanging flyers approved by the Institutional Review Board (IRB) of Drexel University in the community, recruitment from an existing database of individuals with MS who had participated in previous research conducted in the ANT laboratory, and coordination with the National Multiple Sclerosis Society (NMSS). All participants having fulfilled inclusion and exclusion criteria were enrolled in the study and completed informed consent procedures approved by the IRB. Participants took part in one research visit, which was about three hours in length and took place in the ANT laboratory within Drexel University. The research visit included collection of demographic and disease symptom information via participant report, a motor examination, administration of a neuropsychological battery (including the SET and VMT), and completion of questionnaires. Participants were offered rest periods over the research visit to counteract the possible effects of fatigue. Additionally, change in level of fatigue was monitored by having participants rate their fatigue level both before and after testing. Administration of the SET and VMT was counterbalanced. All participants were compensated \$50.00 for participating in the study.

Following final data collection, databases containing the variables of interest were created. Variables were categorized as follows: 1) demographic information, 2) physical data, 3) neuropsychological data, and 4) questionnaire data. Participants were identified with a subject number in the study database to ensure protection of privacy.

2.6 Specific Aims, Hypotheses, and Statistical Analyses

Aim 1. To develop and validate the Vocational Multitasking Test (VMT), a performance based assessment of multitasking ability to predict vocational functioning.

Hypothesis 1: The VMT will show good internal consistency and inter-rater reliability.

Planned Statistical Analysis: Internal consistency of the VMT was analyzed by calculating Cronbach's Alpha (α) based on the scoring indices of the VMT. Inter-rater reliability was calculated for each of the scoring indices of the VMT using Cohen's Kappa (κ). Measurement of VMT inter-rater reliability was based on results of two separate scoring sessions performed by different trained raters: 1) scoring during live observation, and 2) scoring while watching video playback of participant's performance. Calculation of both Cronbach's Alpha and Cohen's Kappa were based on the entire study sample ($n = 38$).

Hypothesis 2: Performance on the VMT will be significantly correlated with performance on the SET, indicating good concurrent validity.

Planned Statistical Analysis: Spearman's rho correlations were conducted to examine the relationship between the VMT and SET. Spearman's rho correlations were used given that the VMT variables did not meet criteria for normality. Total Overall SET score was used to measure performance on the SET, and VMT performance was measured with the following variables: 1) VMT Overall Score, 2) VMT Intrusion Errors, 3) VMT Repetition Errors, 4) VMT Omission Errors, 5) VMT Sequencing Errors, 6) VMT Total Errors, 7) VMT Switch, 8) VMT Switch & Attempted, 9) VMT Total

Changes, 10) VMT Simultaneous. Analyses were two-tailed and alpha level was set at .05.

Hypothesis 3: VMT performance will be significantly correlated with performance on traditional measures of executive functioning, processing speed, episodic memory, and working memory in individuals diagnosed with MS and in HC participants.

Planned Statistical Analysis: Spearman's rho correlations were conducted to assess the relationship between performance on the VMT and traditional neuropsychological measures. VMT performance was measured with four variables: 1) VMT Overall Score, 2) VMT Simultaneous, 3) VMT Total Changes, and 4) VMT Total Errors. Only four performance variables from the VMT were included in the analysis to limit the risk of Type I error. Further, these four VMT variables were selected because they were hypothesized to provide the most informative characterization of VMT performance (i.e., errors, speed and accuracy of task performance, task switching). Neuropsychological measures included in the analyses were: 1) PASAT-Total, 2) SDMT-Total, 3) CVLT-II Immediate Recall Total, 4) CVLT-II Delay Recall Total, 5) Digit Span, 6) TMT-A, and 7) TMT-B. Raw scores on neuropsychological measures were converted to T scores (Heaton & Marcotte, 2000; Silverberg & Millis, 2009) and analyses were conducted separately for MS and HC groups.

Hypothesis 4: Individuals diagnosed with MS will demonstrate worse performance on the VMT relative to HC participants, with significantly lower overall total score, higher number of errors, lower number of simultaneous task attempts, and lower number of total task changes.

Planned Statistical Analysis: Mann-Whitney tests (Mann & Whitney, 1947)

were used to evaluate differences between MS and HC groups on the VMT variables.

Mann-Whitney tests were used in the current analysis given that the VMT variables were not normally distributed. Effect sizes for the Mann-Whitney analyses were estimated with r (Rosenthal, 1991). For each comparison, the median value of the variables of interest will be reported given that this statistic is more appropriate than the mean for non-parametric tests (e.g., Mann-Whitney test). Analyses were one-tailed and alpha level was set at 0.05.

Aim 2: To examine the validity of the VMT to predict vocational outcomes in MS.

Hypothesis 5: Performance on the VMT will be significantly associated with MER value, demonstrating ecological validity.

Planned Statistical Analysis: Among the MS group, Spearman's rho correlations examining the association between MER value and the ten VMT variables of interest were calculated. Effect size (R^2) was calculated for statistically significant correlation coefficients. Analyses were two-tailed and alpha level was set at 0.05.

Hypothesis 6: Performance on the VMT will be significantly associated with Absenteeism and Presenteeism scores on the WHO-HPQ, demonstrating ecological validity.

Planned Statistical Analysis: Among the MS group, Spearman's rho correlations examining the association between Absenteeism score and VMT performance variables were calculated. Similarly, Spearman's rho correlations were conducted to examine

relationships between Presenteeism score and VMT performance variables. Effect size (R^2) was calculated for statistically significant correlation coefficients. Analyses were two-tailed and alpha level was set at 0.05.

Hypothesis 7: Compared to traditional neuropsychological tests, the VMT will explain additional variance in vocational outcomes, demonstrating incremental validity.

Planned Statistical Analysis: Logistic regression analysis was performed to examine the overall contribution of neuropsychological performance and VMT performance to vocational functioning in the MS group. Vocational functioning was defined by categorization of participants with MS into FME and ME groups. Given that fatigue has been shown to be associated with vocational functioning in previous studies (Morse et al., 2013), level of self-reported fatigue interference was entered in the regression model. Additionally, Global Deficit Score (GDS) and VMT Overall Score were entered as predictors into the regression model. Beta values of each predictor variable were reported. Odds ratio was reported as an estimate of effect size. Logistic regression assumptions of linearity, multicollinearity, and independence of errors were evaluated.

3: Results

3.1 Analytical Strategy

All analyses were performed using PASW 18.0. Analyses in the current study used descriptive analyses, comparison of group means, correlations, and logistic regression. Descriptive analyses were performed for demographic variables, neuropsychological measures, the VMT, and psychosocial outcome variables. To

compare demographic variables between MS and HC groups, independent t -tests and chi-square (χ^2) analyses were used.

Scores on neuropsychological measures were converted to T scores to facilitate examination of the distribution of scores. The distribution of all variables was tested for normality using skewness and kurtosis statistical tests. Non-parametric tests were used in instances where variables did not meet criteria for normality. The data was examined for presence of outliers, and no outliers were identified. Non-directional hypotheses were tested using two-tailed tests and directional hypotheses were one-tailed. The criterion for statistical significance in all analyses was $p < .05$.

3.2 Aim 1: Pilot Phase of VMT Development

Development and standardization of VMT administration and scoring procedures was the first step of specific aim one. To achieve this, a total of 10 healthy control adult individuals were administered the VMT. Mean age of participants was 40 years ($SD = 15.13$), and mean education was 15 years ($SD = 2.11$). The pilot sample was 60% female ($n = 6$) and 40% male ($n = 4$). These individuals were seen for only one session and were administered only the VMT. In the session, participants performed the VMT while the lead investigator scored performance. See pages 46-60 of the manual for a sample of completed scoring procedures and task stimuli based on performance of the final pilot participant.

Following completion of the VMT, pilot participants were administered a questionnaire to obtain feedback about the task. Together, participant feedback and

observations of participant performance informed modifications made to the VMT. In sum, the final VMT reflects four main modifications from its original form.

- First, the Office Supplies task was developed in place of a previous Email Management task. It was determined that the specific type of online email account used by individuals was variable and would likely have introduced variability into performance that was specific to navigation of the online email account. The Office Supplies task was used in place of the Email Management task because of the relatively universal procedures for engaging in online shopping. Additionally, the Office Supplies task involved similar demands as the Email Management task, including category flexibility, problem solving, processing information, and interacting with a computer.
- Second, the Time Sheet task was developed in place of the Organizational Spreadsheet task. These two tasks are similar in that they both require comprehension of written information that is then organized based on specified criteria. However, the Time Sheet task involves completing a standard worksheet to calculate hours worked that is likely familiar to participants, whereas the Organizational Spreadsheet involved a novel format that likely would have introduced task specific variance into performance not relevant to the overall construct of multitasking ability.
- Third, pilot participants provided feedback that the Advanced Finances task was too challenging. The examiner noted that pilot participants were spending an extended amount of time on the Advanced Finances task due to the complexity of the task involving multiple components (i.e., calculating amount owed for each

check, writing each check, completing account deposit form, and balancing checkbook). To modify the Advanced Finances task, the component of completing the account deposit form was removed. This reduced the load of the Advanced Finances task and facilitated more engagement in the other tasks.

- Finally, the variable measuring task switching was delineated into “task switches” and “task switch and attempts” to account for differences in behavior when participants were observed to switch their visual gaze between tasks (i.e., task switch) and alternatively when they switched visual gaze and completed at least one action item of another task (i.e., task switch and attempt).
- The four described modifications were integrated into the finalized version of the VMT, which was then administered to study participants for the formal analyses. The modification were made after five pilot participants had been administered the VMT. This allowed for testing of the modifications on five subsequent pilot participants to ensure that the modified procedures were useful and appropriate.

3.3 Aim 1: Formal Analyses

For the formal analyses, thirty-eight of 45 persons who underwent initial assessment protocol met inclusion and exclusion criteria specified previously and consented to participate in the study. Of the individuals not meeting criteria, four exceeded the age requirement, two individuals were not on a stable regimen of medications, and one individual declined entry into the study due to transportation barriers.

3.3.1 General Demographics

The sample for the final analyses consisted of 18 participants with a diagnosis of MS confirmed through participants' treating neurologist and 20 healthy control participants. Within the MS sample, participants' mean age was 52.29 (SD = 7.26) and mean education was 15.24 (1.89). The MS sample was 82% female and 18% male, consistent with reported prevalence rates for gender differences in MS. Self-identified ethnicity among the MS sample was 11% African-American ($n = 2$), 6% Hispanic ($n = 1$), and 83% Caucasian ($n = 15$), which is consistent with reports of higher MS disease prevalence in Caucasian individuals. Mean age among the HC sample was 48.05 (SD = 11.59) and mean education was 15.50 (SD = 2.54). The HC sample was 80% female and 20% male. Additionally, the HC sample was 70% Caucasian ($n = 14$) and 30% African-American ($n = 6$). Comparison of group means using independent means t -tests between MS and HC groups demonstrated that age and education level were not significantly different between groups. Chi-squared analyses confirmed that MS and HC groups did not significantly differ in gender and ethnicity variables. Overall, the HC group was matched to the MS group in age, education, gender, and ethnicity.

3.3.2 Clinical Demographics

Verified by records from treating neurologists, 72% ($n = 14$) of participants with MS had a confirmed diagnosis of Relapsing Remitting disease type, 11% ($n = 2$) were diagnosed with Primary Progressive subtype, 5.6% ($n = 1$) were diagnosed with Secondary Progressive subtype, and 5.6% ($n = 1$) were diagnosed with Primary Relapsing subtype. Compared to the HC group ($M = 5.20$, $SD = 1.49$), participants in the MS group ($M = 6.90$, $SD = 1.89$) demonstrated significantly more impairment in lower

extremity functioning ($t(33) = 2.26, p = .03$). No significant differences were noted between the MS and HC groups on bilateral fine motor speed/coordination. Average disease severity as measured with the MSFC was 0.24 (SD = 0.53), and scores ranged from -1.31 to 1.24. This range of MSFC scores suggests that about 90% of the possible range in MS symptom severity was represented in the current study. Participants were diagnosed with MS an average of 11.88 (SD = 7.60) years prior to the study and experienced symptom onset an average of 13.84 (SD = 10.12) years ago.

3.3.3 Psychosocial Outcome Measures

Depression symptoms were measured with the CMDI. Mean CMDI total score among the MS sample was 105.63 (SD = 15.88) and mean Mood CMDI subscale score was 49.07 (SD = 7.64). Among the HC sample, mean CMDI total score was 88.99 (SD = 9.07) and mean Mood CMDI subscale score was 44.61 (SD = 3.97). Significant differences were demonstrated between MS and HC groups in both CMDI total score ($t(34) = 3.83, p = .001$) and Mood CMDI subscale score ($t(34) = 2.19, p = .04$). In sum, participants in the MS group reported a greater severity of overall depression symptoms, including mood specific symptoms (e.g., sadness, hopelessness).

Average level of reported fatigue interference was 4.47 (SD = 1.60) in the MS group and 2.46 (SD = 1.17) in the HC group. Comparison of fatigue interference levels between MS and HC participants yielded a significantly higher level of fatigue interference in participants with MS ($t(34) = 4.27, p < .001$).

3.3.4 Vocational Outcome Measures

Three methods were used to characterize vocational functioning in the current study. First, a frequency analysis of employment status in the MS group was conducted.

All participants in the MS sample were employed (i.e., working full-time or part-time at the same job for at least six months) at the time of diagnosis. Among MS participants, fifty percent ($n = 9$) have failed to maintain the same level of employment since their diagnosis (FME), and fifty percent ($n = 9$) have maintained employment since their diagnosis (ME). Participants in the FME group reported working an average of 20.42 hours per week, while participants in the ME group reported working an average of 38.32 hours per week. Among participants in the FME group, an average of 12.5 years has passed since their change in employment status (i.e., decrease in hours worked and/or responsibilities).

The second method of characterizing vocational functioning in the MS sample was through calculation of the Monthly Employment Ratio (MER; Wehman et al., 1993). Overall MER value for the MS group was calculated by averaging each individual MER value per participant. Overall MER value for the MS sample was 0.79, indicating the proportion of time since diagnosis that participants spent working without reducing their work hours or responsibilities.

Finally, the World Health Organization Health and Performance Questionnaire (WHO HPQ; Kessler et al., 2003) was used to characterize vocational functioning. Average absenteeism and presenteeism scores (ranging 0-100) were calculated from the WHO-HPQ for the MS and HC groups. See Table 3 for WHO-HPQ scores and analyses demonstrating that participants in the MS group reported significantly higher absenteeism from work compared to the HC group.

3.3.5 Neuropsychological Measures

Descriptive statistics for the traditional neuropsychological outcome measures are summarized in Table 4. Estimated premorbid intellectual ability (i.e., WAIS-III FSIQ) was measured with the Reading subtest of the WRAT-III. Estimated overall intellectual ability for participants with MS was 109.76 (SD = 6.57) and was 104.70 (SD = 8.27) for HC participants. MS and HC groups did not significantly differ in estimated intellectual ability. Raw scores on the traditional neuropsychological measures were converted to age and education normed *T* scores to facilitate comparisons between tests. Independent *t*-tests demonstrated significant differences between MS and HC groups in performance on the SDMT ($p = .03$), TMT B ($p = .03$), PASAT 3" ($p = .03$), and PASAT 2" ($p = .02$). See Table 4 for comparisons of neuropsychological performance between MS and HC groups. As detailed above, an overall estimate of cognitive ability was calculated (i.e., the GDS) by averaging the degree of deficit in performance on each neuropsychological measure. On average, participants in the MS group demonstrated a higher GDS score ($M = 3.95$, $SD = 0.89$) than participants in the HC group ($M = 2.01$, $SD = 0.32$). This difference was significant $t(36) = 4.21$, $p < .05$.

3.3.6 Descriptive Analysis of the VMT

As part of the first study aim, to develop and validate the VMT, descriptive analyses were conducted on the VMT performance variables. Data for the VMT was available for 100% ($n = 38$) of all study participants. See Table 5 for descriptive analyses of the VMT variables among the MS and HC groups. Spearman's rho correlations were conducted across the entire sample to examine relationships between the: 1) VMT Overall Score, 2) VMT Total Errors, 3) VMT Simultaneous, 4) VMT Total Changes, and

5) VMT Plan Time. These five VMT variables were selected to reduce the risk of Type I error and because they are hypothesized to characterize all elements of performance on the VMT (i.e., planning, errors, speed and accuracy of performance, task switching behavior, and simultaneous task attempts). VMT Total Changes was significantly correlated with VMT Overall Score ($r_s = .60, p < .001$) and VMT Simultaneous ($r_s = .73, p < .001$). VMT Overall Score was significantly associated with VMT Simultaneous ($r_s = .44, p < .01$). No other significant associations were demonstrated between VMT variables.

3.3.7 Internal Consistency and Inter-rater Reliability of the VMT

It was hypothesized that the VMT would demonstrate good internal consistency and inter-rater reliability. To evaluate internal consistency, VMT performance variables were entered into the reliability analysis yielding an overall Cronbach's Alpha value (α). Internal consistency for the VMT Overall Score was relatively high with $\alpha = .74$. Additionally, VMT Simultaneous was $\alpha = .68$, VMT Total Changes was $\alpha = .62$, and VMT Total Errors was $\alpha = .43$. Inter-rater reliability was calculated with Cohen's Kappa (κ) to determine the degree of agreement between each of the two ratings of VMT performance. There was strong agreement (Landis & Koch, 1977) between the two raters for VMT Overall Score, $\kappa = .89$ (95% CI, .74 to .93), $p < .001$. Additionally, the average agreement across all VMT variables was strong, which was calculated by averaging all inter-rater reliability values, $\kappa = .85$ (SD = .07).

3.3.8 Concurrent Validity of VMT

To measure concurrent validity of the VMT, Spearman's rho correlations were conducted between Total Overall SET score and all VMT performance variables.

Spearman's rho correlations were conducted due to the non-normality of the VMT performance measures. Total Overall SET was significantly correlated to VMT Total Score ($r_s = .39, p < .05$), VMT Total Errors ($r_s = -.40, p < .05$), and VMT Task Switch and Attempts ($r_s = .43, p < .01$). No other VMT variables were significantly correlated to Overall SET score, although VMT Simultaneous trended toward significance.

3.3.9 Spearman's rho Correlations: VMT and Neuropsychological Measures

It was hypothesized that the VMT would be significantly correlated with measures of executive functioning, processing speed, episodic memory, and working memory in MS and HC groups. Spearman's rho correlations were conducted to examine the relationship between four VMT variables (VMT Overall score, VMT Simultaneous, VMT Total Errors, and VMT Total Changes) and the following neuropsychological variables: 1) PASAT-Total, 2) SDMT-Total, 3) CVLT-II Immediate Recall Total, 4) CVLT-II Delay Recall Total, 5) Digit Span, 6) TMT-A, and 7) TMT-B. Analyses were conducted separately for MS and HC groups to examine differences in relationships across clinical and healthy control samples. See Table 6 for full results of correlational analyses.

Within the MS group, VMT Overall Score was significantly associated with TMT-B, $r_s = .57$, and SDMT-Total, $r_s = .62$ (all $ps < .05$). VMT Total Errors was not significantly associated with any of the neuropsychological variables. VMT Simultaneous was significantly associated with TMT-B ($r_s = .52, p < .05$) and VMT Total Changes was significantly associated with PASAT-Total ($r_s = .49, p < .05$).

Among the HC group, VMT Overall Score was significantly associated with SDMT-Total ($r_s = .52, p < .05$). VMT Total Errors and VMT Simultaneous were not

significantly associated with any neuropsychological variables. VMT Total Changes was significantly associated with SDMT-Total ($r_s = .52, p < .05$).

This initial approach to examining relationships between VMT and neuropsychological performance used demographically corrected scores to measure neuropsychological performance. Given that VMT scores are not demographically adjusted, this approach reduces variance in neuropsychological performance that may be significantly associated with VMT performance. To account for this, Spearman's rho correlations were conducted to examine the relationship between four VMT variables (VMT Overall score, VMT Simultaneous, VMT Total Errors, and VMT Total Changes) and the raw scores of the following neuropsychological variables: 1) PASAT-Total, 2) SDMT-Total, 3) CVLT-II Immediate Recall Total, 4) CVLT-II Delay Recall Total, 5) Digit Span, 6) TMT-A, and 7) TMT-B. Results of this analysis showed that in both MS and HC groups, no additional significant relationships were found between neuropsychological and VMT variables. Relationships shown to be significant using demographically adjusted neuropsychological scores remained consistent.

3.3.10 Comparisons of VMT Performance Across MS and HC Groups

It was hypothesized that participants in the MS group would perform significantly worse on the VMT relative to HC participants. To examine this hypothesis, Mann-Whitney tests were conducted. No demographic variables were controlled for in these comparison analyses given that MS and HC groups did not significantly differ across age, education, and gender. Median value of each variable is reported. VMT Overall Score in the MS group ($Mdn = 33.0$) was significantly lower than in the HC group ($Mdn = 39.50$), $U = 5.32, z = -2.98, p < .01, r = -.68$. VMT Total Errors in the MS group ($Mdn = 4.00$)

were significantly higher than in the HC group ($Mdn = 2.00$), $U = 6.12$, $z = -2.34$, $p < .05$, $r = -.61$. VMT Simultaneous score in the MS group ($Mdn = 1.00$) was significantly lower than in the HC group ($Mdn = 3.00$), $U = 6.39$, $z = -2.20$, $p < .05$, $r = -.59$. VMT Total Changes was not significantly between the MS and HC groups. VMT Omission Errors in the MS group ($Mdn = 2.00$) were significantly higher than in the HC group ($Mdn = .00$), $U = 7.10$, $z = -1.85$, $p < .05$, $r = -.55$.

3.4 Aim 2 Analyses

To validate the VMT as a predictor of vocational functioning in Aim 2, VMT performance was compared with vocational outcomes. Finally, a logistic regression model was conducted to predict vocational group status.

3.4.1 Relationship Between VMT and Vocational Functioning

In considering the ecological validity of the VMT, it was hypothesized that performance on the VMT would be significantly associated with vocational functioning, as defined by 1) MER value and 2) Absenteeism and Presenteeism scores on the WHO-HPQ. Spearman's rho correlations were used to examine the relationship between the VMT and MER value. MER value was significantly correlated with VMT Overall Score ($r_s = .40$, $R^2 = 0.16$, $p < .05$) and VMT Total Changes ($r_s = .37$, $R^2 = 0.14$, $p < .05$). No other significant correlations between MER value and the VMT were demonstrated.

Similarly, Spearman's rho correlations were used to examine the relationship between VMT performance variables and Absenteeism and Presenteeism scores.

Absenteeism was not significantly correlated with any VMT performance variables.

Presenteeism was significantly correlated with VMT Simultaneous ($r_s = .65$, $R^2 = 0.42$, p

< .01). No other significant correlations were demonstrated between Presenteeism and VMT performance variables.

3.4.2 Ecological and Incremental Validity of the VMT: Logistic Regression

It was hypothesized that the VMT would explain additional variance in vocational outcomes compared to traditional neuropsychological measures. To explore how much variance in vocational outcome (FME vs. ME) could be explained by the overall model, the contributions of GDS, VMT Overall Score, and FSS were tested using forced entry logistic regression. The three predictors were added to the model together. Results suggested the model was able to successfully classify 69% of cases correctly ($\chi^2(1) = 8.32, p = .04$), with VMT Overall Score [$\text{Exp}(B) = 1.43, p = .03$] and FSS [$\text{Exp}(B) = .79, p = .04$] significantly predicting vocational group status. GDS was not retained as a significant predictor in the model.

4: Discussion

The current study sought to develop the VMT as a performance-based measure of multitasking and to explore its usefulness in predicting vocational functioning in MS. The results from this study provide possible characterization of multitasking abilities in individuals with MS and represent a continuation of a systematic approach to addressing the challenges of predicting vocational outcomes in MS. The study offers two novel contributions to the existing literature; first, it examines multitasking (a complex, functional cognitive construct) which has only begun to be understood in MS and second, it employs a performance-based measure of vocationally relevant tasks. The VMT was developed to address the limitations of existing cognitive measures in predicting real-world functional outcomes. Specifically, given that individuals with MS often demonstrate

more subtle cognitive impairment, the VMT was designed to be a more challenging task to measure multitasking ability in this clinical population. Additionally, the existing measure of multitasking ability in the literature (i.e., the SET) is structured in a manner that does not allow evaluation of a person's ability to plan their time correctly, work efficiently towards completing a goal, and/or engage in multiple tasks simultaneously. To address these limitations, the VMT was developed as a "real-world" model to better reflect multitasking demands one may encounter in the workplace. In the current study, preliminary demonstration of the VMT's good psychometric properties suggests the feasibility of developing ecologically valid measures of multitasking ability to predict performance in the challenging and complex environment of the workplace.

Individuals with MS who exhibited a range of disease severity were included in the sample. Additionally, individuals represented various stages of employment, ranging from a reduction in hours since being diagnosed with MS through maintaining work hours. In sum, a wide range of MS participants were included in the current study to enhance generalizability.

The study introduces the VMT and provides evidence for promising psychometric properties for a performance based task. Specifically, the internal consistency of the primary measure of VMT performance (i.e., VMT Overall Score) was satisfactory with an acceptable level of inter-rater reliability. This is comparable with the consistency and reliability of other performance based tasks developed in the literature (Cook, Chapman, & Levin, 2008; Holt et al., 2011, Knight et al., 2002; Dawson et al., 2005). The VMT Simultaneous and VMT Total Changes variables also met criteria for adequate consistency. By contrast, the VMT Total Errors score showed a low internal consistency

value. A possible explanation for this may be that the VMT Errors score reflects a sum of five different error types, each which were made at different frequencies by participants. Thus, there is inherent reduced internal consistency in the VMT Errors variable. Overall, the acceptable internal consistency and inter-rater reliability of the VMT contributes to the growing body of literature demonstrating the possibility of strong psychometric properties for performance based measures (Burgess et al., 2006).

Further exploration of the psychometric properties of the VMT revealed significant relationships between the VMT and the SET, the only measure of multitasking ability that has been validated in the literature. The significant associations demonstrated between the various SET performance and VMT variables suggests that the VMT may be useful in characterizing multitasking ability. Of note, the frequency of simultaneous task engagement on the VMT trended toward a meaningful correlation with SET performance although it did not reach statistical significance. Although not statistically significant, this relationship lends further support for the usefulness of the VMT in characterizing multitasking ability. Differences in methodological design between the VMT and SET may account for the absence of a significant relationship between the SET and simultaneous task engagement on the VMT. One consideration is the overall difference in the demands of the two tasks, where the SET relies on the completion of discrete tasks and the VMT allows the opportunity to engage in tasks simultaneously. This difference may be a salient component of defining a complex functional construct like multitasking.

Within the MS sample, overall amount of the VMT completed showed significant associations with measures of processing speed and mental flexibility. Discriminant validity was shown with respect to a measure of verbal memory. The demonstrated

relationship between amount of the VMT completed and processing speed is consistent with findings from a previous study where processing speed was shown to be significantly associated with overall amount of the SET completed (Morse et al., 2013). Replication of the relationship between multitasking performance and processing speed suggests that processing speed may be an important factor contributing to multitasking performance. Of note, processing speed is one of the primary neurocognitive deficits identified in MS (Rao et al., 1991). Further support for the involvement of processing speed in multitasking ability comes from significant associations between processing speed and VMT performance in the healthy control group.

Results showed that additional VMT variables were significantly associated with performance on neuropsychological measures within the MS group. First, frequency of simultaneous task engagement on the VMT was shown to be significantly associated with mental flexibility. On the VMT, the only opportunity to perform tasks simultaneously occurs if a participant engages in another task while using the telephone. Consequently, individuals performing a second task while maintaining an initial task (i.e., telephone task) may be concurrently maintaining two goal oriented sets of behaviors that they need to switch between. Second, a higher number of task switches on the VMT was significantly associated with working memory ability. This suggests that distinct switching between tasks on the VMT requires mental manipulation of information. Thus, in addition to processing speed, multitasking ability in the MS group was significantly associated with mental flexibility and working memory. Unlike the prior study where no significant relationships were found between performance on the SET and measures of executive functioning (Morse et al., 2013), the current study showed that the VMT

captures elements of executive functioning (i.e., mental flexibility and working memory). This is important from a vocational perspective given the demands on higher level executive functioning abilities in the workplace (Benedict et al., 2005).

Across all VMT variables, no significant associations were demonstrated with verbal memory ability. Given that Burgess and colleagues (2000) showed that multitasking ability was significantly associated with retrospective memory, planning ability, and prospective memory, the lack of significant association between the VMT and verbal memory is surprising. Absence of a relationship may be due to the design of the VMT, which limits demands on memory by providing participants with a written summary of task rules throughout the VMT. In support of this, 85% of participants in the study indicated they relied on visual task instructions either “somewhat” or “very much”. Additionally, the absence of significant associations between VMT variables and the measure of attention used in the current study is surprising given that multitasking ability clearly places demands on attention. This may be related to the comparatively simple and clearly defined characteristics of the attention measure used, which differs from the more complex attention demands of the VMT.

In examining the various relationships across individuals with and without MS, it is remarkable that a greater number of associations between VMT performance and neuropsychological measures were observed within the MS group relative to the healthy control group. In the MS group, mental flexibility, working memory, and processing speed were significantly associated with VMT performance. By contrast among the control group, only processing speed was significantly associated with VMT performance. This may suggest that multitasking is more cognitively demanding for

individuals with MS, whereas healthy control participants may only be recruiting fundamental constructs such as processing speed.

In the previous study conducted by Morse and colleagues (2013), multitasking performance was significantly associated with only one cognitive domain, i.e., processing speed. This may raise questions that measures of multitasking ability are just semantically framed tests of processing speed. However, in the current study performance on the VMT was significantly associated with processing speed, mental flexibility, and working memory. This argues that although involved, processing speed is not the dominating factor contributing to performance on the VMT. Rather, successful performance requires integration of multiple cognitive abilities (i.e., mental flexibility, working memory, processing speed), which may be more reflective of the real-world environment. In this way, the VMT is consistent with the criteria described by Burgess and colleagues (2006) for ecologically valid tests of executive functioning. Burgess and colleagues (2006) note the previous assumption made in research that analytical power can be maximized by minimizing variability and isolating specific factors to be measured. However, Kingstone and colleagues (2005) argue against this by suggesting that important characteristics of cognition are nonlinear and are only revealed when several variables vary together in specific ways. Thus, given that the VMT appears to involve multiple cognitive processes, it may provide a more ecologically valid measure of multitasking.

Individuals with MS performed worse than healthy control individuals on overall amount of the VMT completed, and on three of the additional VMT variables; VMT Simultaneous, VMT Total Errors, and VMT Omission Errors. It is important to note, that

across the multiple VMT metrics, the MS group accurately completed significantly fewer actions steps of the VMT, made fewer simultaneous task attempts, and made significantly more total errors and the specific type of omission error. The presence of group differences across multiple VMT measures lends support that the VMT is particularly sensitive to aspects of cognitive functioning that appear critical to vocational success among individuals with MS. This demonstration of differences in multitasking performance on the VMT between individuals with MS and healthy control individuals is a novel contribution to the existing literature.

One prior study in the literature has examined differences between individuals with MS and healthy control individuals on a performance based functional assessment measure termed the Actual Reality task (Goverover, O'Brien, Moore, & DeLuca, 2010). Although the Actual Reality task was not developed as a measure of multitasking ability, the task uses a performance-based approach similar to the "real world" model of the VMT. Briefly, the Actual Reality task measures a participant's ability to use the internet to purchase an airline ticket. The authors found that the MS group required significantly more cues to complete the task, made significantly more errors, and were significantly more impaired in completing action steps on the task. Additionally, performance on the Actual Reality test was not significantly correlated with self-reported difficulties with activities of daily living, which is consistent with other studies demonstrating that self-report of everyday functional activity is not significantly correlated with actual everyday functioning in MS (Goverover et al., 2005; Kalmar, Gaudno, Moore, Halper, & DeLuca, 2008). This argues for the importance of considering both subjective self-report measures and objective performance based measures in evaluating functional abilities.

Results of the current study are consistent with the findings by Goverover and colleagues (2010) suggesting that performance based assessment has the potential to significantly improve the assessment of everyday functioning in MS.

Further comparison of VMT performance demonstrated that the MS group made significantly more total overall errors and omission errors on the VMT than the healthy control group. Additionally, across multiple measures of the VMT, the MS group consistently underperformed the control group. An increase in errors when time to complete performance based measures is restricted is a common pattern that has been replicated with individuals with MS and other clinical populations. In the MS population, Schultheis and colleagues (2010) demonstrated that information processing speed was the strongest predictor of behind-the-wheel driving performance, where slower processing speed was associated with more errors while driving. Another study demonstrated that individuals with traumatic brain injury (TBI) made more frequent omission errors on the Multi-Level Action Test (MLAT; Schwartz et al., 1998), a performance based measure requiring individuals to make a slice of toast with butter and jam, wrap a present, and pack a lunchbox. Within the pediatric literature, this relationship has been demonstrated in a study with brain-injured children using a performance based measure of executive functioning termed the “Birthday Task” (Cook, Chapman, & Levin, 2008). The “Birthday Task” is similar to the MLAT in that participants perform three tasks while following designated rules: 1) making two peanut butter and jelly sandwiches, 2) gift-wrapping two presents, and 3) preparing a birthday card. Children with TBI (ages 8-16) demonstrated significantly increased use of distractor objects instead of target objects and higher rates of omitting task steps. In sum,

results of the current study are consistent with past literature demonstrating an increase in omission errors when time to complete performance based measures is restricted.

A possible reason for decreased performance on the VMT in the MS group could be related to the theory of the supervisory attentional system, which is said to direct cognitive processing in novel situations, particularly when certain responses or actions must be avoided (Norman & Shallice, 1986). The supervisory system is hypothesized to be seated in the prefrontal cortex and is activated when a task cannot be adequately executed through the application of well-learned action patterns. In this way, planning processes in everyday activities occur “on-line” as opportunities or difficulties arise in one’s environment. Critical aspects of the cognitive systems that support multitasking behaviors have been shown to also be components of the supervisory attentional system (Shallice & Burgess, 1991). Self-regulation of action with the supervisory attentional system requires adherence to both external restrictions and internal goals (Shallice & Burgess, 1991); in the VMT successful performance requires inhibiting responses by adhering to novel rules and resisting distracting elements. Thus, decreased performance on the VMT for individuals with MS may reflect inefficiencies in the supervisory attention system.

The findings from this study are the first to demonstrate a relationship between VMT performance and real-world functioning in the workplace; specifically measures of attendance at work (Presenteeism) and a vocational rating (MER). Interestingly, VMT performance was significantly associated with self-reported productivity at work, whereas performance was not significantly associated with days missed from work due to MS disease burden. This suggests that the VMT may be more helpful in predicting one’s

capacity and productivity at work rather than work missed due to MS symptoms. A relationship was seen between more frequent engagement in simultaneous tasks on the VMT and productivity at work. This suggests that individuals with MS who are able to maintain two goal directed behaviors at the same time are also more productive at work. Although number of days missed from work was not significantly associated with VMT performance, on a more macro level the length of time individuals worked before reducing their work hours since being diagnosed with MS was significantly associated with VMT performance (i.e., VMT Overall score and VMT Total Changes).

Analysis of the incremental validity of the VMT demonstrated that the VMT may be a useful predictor of vocational functioning and may provide novel information for informing vocational decision making. In the predictive model, vocational functioning status was defined as either having reduced work hours since diagnosis with MS or having maintained the same level of work hours since diagnosis. Performance on the VMT, in combination with self-reported fatigue, was able to predict vocational group status with 69% accuracy. Importantly, performance on neuropsychological tests was not shown to be a significant predictor of vocational group status. This suggests the utility of the VMT in approximating vocational functioning status, and further that it may be a more useful measure than traditional neuropsychological tests.

There may be several reasons the VMT accounted for more variance in vocational status than neuropsychological tests. Performance on tests with high representativeness of the function they are attempting to predict have been shown to be more predictive of real world performance than traditional tests (Alderman et al., 2003; Burgess et al., 1998; Wilson et al., 1998). The disparity between the demands of real-life and the

testing/laboratory environments of traditional tests may account for this. Importantly, a performance based test is not necessarily more clinically useful because it resembles the real world; instead Burgess (2000) argues that performance based tests are useful when the demands of the real world that are not already being measured by existing traditional tests are integrated into the test. In this way, it can be argued that the VMT allowed for strategic thinking, balancing priorities, and development of a strategy to engage in multitasking. Additionally, over the course of the VMT participants must determine the pace of engagement in the tasks and do not receive feedback for a relatively long period of time. This differs from the structured nature of traditional neuropsychological tests where performance is influenced by greater external architecture implemented by the examiner and shorter timeframes for task completion. Further, the face validity of the VMT may have motivated participants to engage more as it was similar to real-life situations they encounter. When queried how much the demands of the VMT felt similar to an average workday, 74% of participants endorsed a “3” or “4” on a five point scale ranging from 0 to 4 with higher scores indicating a greater degree of similarity.

Taken together, the findings offer a promising new model for providing new insight into vocational functioning in MS. Factors of multitasking ability, fatigue, and neurocognitive functioning were considered as predictive of vocational functioning. However, the multi-faceted and complex nature of vocational functioning suggests that additional variables such as transportation barriers, marital status, degree of physical disability, flexibility and nature of job demands, and socioeconomic status may also impact vocational outcomes in MS. To this point, all variables that may potentially impact vocational functioning can be conceptualized as either internal (e.g., originating

from within individual) or external factors (e.g., products of an individual's environment). An internal factor that was shown to impact vocational functioning in the current study was fatigue. In MS, cognitive fatigue, defined as decreased performance during acute and sustained mental effort (DeLuca et al., 2008), varies based on individual differences in disease severity. In this way, cognitive fatigue is influenced by factors originating from the individual. Alternatively, multitasking ability is an externally driven factor in that it is only required when the external environment is time restricted and demands task switching. Thus, the need to engage in multitasking can be reduced by altering one's environment, which offers clinicians an opportunity for intervention by restructuring the demands of one's workplace to limit the need for multitasking.

4.1 Clinical Implications

The overarching goal of the current study was to develop a novel and improved measure of multitasking ability to help define the specific challenges faced by individuals with MS in the workplace and to ultimately begin to inform rehabilitation efforts to maintain vocational status. Maintaining employment is related to overall better quality of life for individuals with MS and has physical, emotional and social benefits. Currently, there are few informative tools that can help clinicians predict the barriers faced by individuals with MS for maintaining employment and subsequently, even less tools for vocational rehabilitation. The current study demonstrated that the VMT is a valid and reliable measure of multitasking ability and that it may be a better predictor of vocational functioning than traditional neuropsychological performance. These promising results suggest that the VMT may be useful for application in the rehabilitation setting. The VMT is easy to administer and variables generated from the VMT allow for

characterization of the different components of multitasking ability. Clinically, the face validity of the VMT may make patients more likely to accept feedback about cognitive symptoms when the assessment measure used to make decisions about their impairment is more reflective of their everyday environment. The limited physical demands of the VMT also make it suitable for the MS population and other clinical populations with motor dysfunction.

In contrast to existing measures of multitasking, the VMT allows a clinician to measure various different aspects of multitasking ability (e.g., switching behavior, accuracy, simultaneous task attempts, etc.). Consideration of which particular aspects of an individual's VMT performance are impaired can offer new opportunities for generating cognitively-defined rehabilitation interventions that attempt to compensate for multitasking deficits. Furthermore, the VMT could be manipulated to test the effectiveness of possible compensatory strategies. This approach has been validated with individuals diagnosed with Alzheimer's disease (AD) on the Naturalistic Action Test (NAT; Giovanetti et al., 2007). Specifically, researchers demonstrated that modifying the original NAT to include visuo-spatial aids and verbal cues improved performance on the task, providing information to guide clinicians in rehabilitation interventions.

Utilizing this approach with the VMT, one possible compensatory strategy could be to allot additional time to complete the four tasks of the VMT (i.e., an additional eight minutes from the standard VMT). Another compensatory modification could be to implement a five minute planning phase where individuals complete a structured worksheet cuing them to plan the order tasks will be performed and at what time intervals they will switch tasks. The results could potentially help define evidenced-based

recommendations to improve vocational interventions aimed at helping people maintain their vocational status longer.

An important factor when considering the future clinical usefulness of the VMT would be to evaluate the continued relevance of the VMT tasks as time progresses. In other words, methods need to be considered for how to maintain the ecological validity of the VMT tasks within the context of evolving technology. For example, many participants report engaging in online banking as opposed to balancing checkbooks by hand or using mobile phone with more advanced computing capability and connectivity than basic feature phones. Perhaps one avenue for the future direction of the VMT would be to develop a technology-adapted version of the VMT to be performed on a mobile phone.

4.2 Limitations

Despite the encouraging findings, there are several limitations to this first study that warrant further discussion. One potential limitation of the current study is the relatively small sample size used for formal analyses. Although adequate power was achieved to detect true statistical differences in analyses, a larger sample size would allow a greater number of variables to be examined in the model predicting vocational functioning. It would also reduce the risk of Type I error by increasing power to allow for Bonferroni corrections to be conducted. Additionally, a larger sample size would allow recruitment of individuals who are unemployed at the time of the study, which could increase generalizability of the results. Future studies should utilize a larger sample size in continued examination of the psychometric properties and ecological validity of the VMT.

Second, the face validity of the VMT was limited somewhat by the absence of distractor items among the stimuli presented to the participant. Instead, participants were only presented with materials that were required or useful in completing the VMT. This contrasts to the MLAT, another performance based measure of executive functioning, where distractor items are among the target objects presented to the participant (Schwartz et al., 1998). Schwartz and colleagues (1998) found that distractor items were used more frequently by individuals with TBI than normal controls. The authors hypothesized that this was due to a reduction in top-down processing, which is driven by goal based actions. A reduction in top-down processing consequently required individuals with TBI to rely on bottom-up processing, which takes place continuously and involves perception of what objects are available to complete a task (Fuster, 1989). In these instances when bottom-up processing has a greater influence on behavior the likelihood of a substitution error increases. Additionally, substitution errors have been shown to be associated with decreased semantic knowledge (Giovannetti et al., 2002), although impaired semantic knowledge is not commonly reported in MS. So it is possible that even in the presence of distractor objects, individuals with MS would not engage in significantly more substitution errors. Future studies should integrate related distractor objects (e.g., multiple web browsers open on the laptop, various time sheets from different pay periods) into the VMT to evaluate for possible associated changes in frequency of substitution errors.

Face validity of the VMT could also have been improved by incorporating emotional control variables into performance, such as the ability to tolerate frustration and receive criticism from coworkers and supervisors. An early study by Butler and

colleagues (1987) demonstrated an approach to incorporating these variables into a performance based task. In the study, participants completed the Behavioral Assessment of Vocational Skills (BAVS), which involved assembling a wheelbarrow while two raters role-played supervisor personnel. As participants assembled the wheelbarrow, the raters assumed more direct roles by distracting participants with a brief alternate task to complete and providing criticism about the participant's performance when an error was made. Participants were rated on their ability to persist when frustrated, control emotions at challenging times, and react appropriately to criticism from a supervisor. Future performance based measures should consider incorporating measurement of emotional and behavioral control into task performance as these are important variables that likely influence functioning in the workplace.

In consideration of future modifications to the VMT, the number of "self-corrections" of mistakes participants made on the VMT was not characterized in the current study. That is, if a participant recognized when an error had been made and subsequently made corrections for the error, this was not counted as an error. Future studies should incorporate "self-corrections" into VMT scoring procedures to characterize this self-monitoring behavior. A potential future hypothesis regarding self-corrections is that a greater number of self-corrections would be associated with improved performance on neuropsychological measures of executive functioning.

A third limitation of the current study was that self-reported depression symptoms were not included in the regression model to predict vocational functioning. Due to limitations in power, only three predictor variables (i.e., VMT, neuropsychological performance, and fatigue) were entered into the regression model. Fatigue was selected

as a predictor variable given the results from the prior study conducted by the author showing that fatigue was a significant unique predictor of vocational functioning (Morse et al., 2013). Further, in studies examining reasons reported for premature retirement in individuals with MS, fatigue was reported as one of the four main physical symptoms (Kornblith et al., 1996; Verdier-Tailefer et al., 1995). Additional studies have reported that higher perceived fatigue level is the most significant predictor of unemployment (Edgley et al, 1991; Jackson et al., 1991). In the current sample, individuals with MS reported mild levels of depression, which is consistent with documented levels of depression in MS in the existing literature (Arnett et al., 1999). The mild level of depression reported was not of a magnitude that would be expected to be associated with significant psychomotor slowing that could impair speed of performance on the VMT. Future studies with larger samples should examine the relationship between depression and vocational outcomes.

In addition to depression symptoms, future studies should consider the relationship between measures of personality and vocational outcomes. Rumrill (1996) has proposed that self-efficacy moderates the relationship between MS and vocational outcomes. This theory notes that coping with MS while maintaining a career requires a person to take an active role in overcoming disability-related work limitations. Further, that individuals with MS who do not believe they possess the skills required to remove or reduce work-related barriers or do not have confidence that such actions would result in a desirable outcome will have worse vocational outcomes. Thus, it is hypothesized that personality factors would be associated with vocational functioning in MS. Future

studies with the VMT should incorporate measurement of personality factors in a regression model predicting vocational outcomes.

Fourth, in the current study vocational functioning was characterized by amount of time spent in the workforce since MS and number of hours worked while employed. Although this study was the first to employ measurements of Absenteeism and Presenteeism in the MS literature, characterization of vocational functioning could be further improved by considering factors of “underemployment” Underemployment is defined as the employment of individuals in positions that that under represent their education, skill level, and experience (Bureau of Labor Statistics, 2012). As this is a recent trend being reported in the United States labor force, it would be useful in future studies to assess for its presence and effect in individuals with MS.

Finally, the absence of diversity in the MS group should be acknowledged. In the current study, the ethnicity of participants with MS was primarily Caucasian and mean education level was high. These characteristics can insert sample bias into interpretation of the current findings due to the potential protective factors shown to be associated with high levels of education (e.g., high median income, higher SES). However, this selection bias is not specific to the current study, but rather is representative of many MS samples recruited for participation in research. Schwartz and Fox (1995) examined this selection bias in the MS literature to measure whether individuals’ sociodemographic and medical characteristics were associated with participation in a randomized control trial of two psychosocial interventions. Results showed that individuals with higher median family income, who lived a moderate distance from the research facility, and were disabled from working were more likely to participate in successive stages of recruitment. Efforts were

made in the current study to increase diversity of the MS sample, including recruitment at a community event sponsored by the National Multiple Sclerosis Society (NMSS) and two Philadelphia based hospitals. Future efforts to increase the diversity of recruitment samples should involve reaching out to the African American Advisory Council and Hispanic/Latino Advisory Council of the NMSS for suggestions on recruiting efforts (NMSS, Retrieved from <http://www.nationalmssociety.org/Resources-Support/Resources-for-Specific-Populations>).

Despite these limitations, the overarching strengths of this study were the development and validation of a novel performance based measure of multitasking ability and identification of the VMT as a predictor of vocational functioning. These results contribute to the growing literature demonstrating the ecological validity of using performance based measures in combination with traditional neuropsychological measures to predict functional outcomes. Future study should continue to explore the usefulness of the VMT as a measure of multitasking ability in predicting vocational outcomes in MS, and should expand study to include other clinical populations.

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Appendix A. O*NET General Worker Activities

1. Getting Information
2. Monitor Processes, Materials, or Surroundings
3. Identifying Objects, Actions, and Events
4. Estimating the Quantifiable Characteristics of Products, Events, or Information
5. Judging the Qualities of Things, Services, or People
6. Processing Information
7. Evaluating Information to Determine Compliance with Standards
8. Analyzing Data or Information
9. Making Decisions and Solving Problems
10. Thinking Creatively
11. Updating and Using Relevant Knowledge
12. Developing Objectives and Strategies
13. Scheduling Work and Activities
14. Organizing, Planning, and Prioritizing Work
15. Interacting With Computers
16. Documenting/Recording Information
17. Interpreting the Meaning of Information for Others
18. Performing for or Working Directly with the Public
19. Performing Administrative Activities
20. Monitoring and Controlling Resources
21. Communicating with Supervisors, Peers, or Subordinates
22. Communicating with Persons Outside Organization
23. Establishing and Maintaining Interpersonal Relationships
24. Assisting and Caring for Others
25. Selling or Influencing Others
26. Resolving Conflicts and Negotiating with Others
27. Coordinating the Work and Activities of Others
28. Developing and Building Teams
29. Training and Teaching Others
30. Guiding, Directing, and Motivating Subordinates
31. Coaching and Developing Others

Note. From U.S. Department of Labor, National O*NET Consortium. O*NET OnLine

Appendix B. O*NET General Worker Cognitive Abilities

1. Oral comprehension
2. Written comprehension
3. Oral expression
4. Written expression
5. Fluency of ideas
6. Originality
7. Problem sensitivity
8. Deductive reasoning
9. Inductive reasoning
10. Information ordering
11. Category flexibility
12. Mathematical reasoning
13. Number facility
14. Memorization
15. Spatial orientation
16. Visualization
17. Selective attention
18. Time sharing

Note. From U.S. Department of Labor, National O*NET Consortium. O*NET OnLine

Table 1. Theoretical Development of VMT Component Tasks

VMT Task	Original Scott et al. (2011) Task	Relevant O*NET (2008) Worker Abilities and Activities
Advanced Finances	<p><i>Advanced Finances:</i></p> <p><u>Consistencies</u></p> <ul style="list-style-type: none"> • Paying three bills • Balancing checkbook to leave specific amount of money in final balance • Requiring participant to call credit card company to dispute a charge before initiating task • Length of task • Scoring procedures <p><u>Modifications</u></p> <ul style="list-style-type: none"> • Company finances as opposed to personal finances • No management of account deposit 	<p><u>Worker Abilities</u></p> <ul style="list-style-type: none"> • Mathematical reasoning, number facility, written comprehension, and deductive reasoning <p><u>Worker Activities</u></p> <ul style="list-style-type: none"> • Processing information, analyzing data, solving problems, monitoring a process
Office Supplies	<p><i>Cooking:</i></p> <ul style="list-style-type: none"> • Office Supplies task was independently developed, and is not a vocational analogue of the cooking task. 	<p><u>Worker Abilities</u></p> <ul style="list-style-type: none"> • Information ordering, category flexibility, selective attention, time sharing, fluency of ideas, problem sensitivity <p><u>Worker Activities</u></p> <ul style="list-style-type: none"> • Processing information, solving problems, monitoring a process, getting information, interacting with computers, analyzing information
Time Sheet	<p><i>Medication Management:</i></p> <p><u>Consistencies</u></p> <ul style="list-style-type: none"> • Requires organization of stimuli • Requires interpretation of verbal information • Participant must self-initiate a task switch (phone call) 	<p><u>Worker Abilities</u></p> <ul style="list-style-type: none"> • Written comprehension, written expression, deductive reasoning, category flexibility, information ordering, problem

Table 1 (continued)

	<p><u>Modifications</u></p> <ul style="list-style-type: none"> • Stimuli is a hourly salary time sheet as opposed to medications 	<p>sensitivity, selective attention</p> <p><u>Worker Activities</u></p> <ul style="list-style-type: none"> • Getting information, processing information, analyzing data, interpreting meaning of information, documenting information
	<p><i>Telephone Communication:</i></p> <p><u>Consistencies</u></p> <ul style="list-style-type: none"> • Requires participant to make three phone calls • Provided with three elements to include in each message • Required to search for phone numbers in phone book <p><u>Modifications</u></p> <ul style="list-style-type: none"> • Purpose for phone call and content of message left at each number 	<p><u>Worker Abilities</u></p> <ul style="list-style-type: none"> • Oral expression, verbal comprehension, information ordering <p><u>Worker Activities</u></p> <ul style="list-style-type: none"> • Getting information, identifying objects, actions, and events, performing administrative activities, communication with supervisors, peers, or subordinates, communication with persons outside organization

Table 2. Description of VMT Component Tasks

VMT Task	Description of Task	Total Points	Total Completion Time
Advanced Finances (Heaton et al., 2004; Scott et al., 2011)	<ul style="list-style-type: none"> • Paying three bills by writing three checks • Balancing checkbook to leave specific amount of money in final balance • Instructing participant to call credit card company to dispute a charge before initiating task 	15 points	10 minutes
Office Supplies	<ul style="list-style-type: none"> • Purchasing two items online from a common office supplies • Participants are oriented to Internet browser and webpage to use for purchasing 	13 points	6 minutes
Time Sheet	<ul style="list-style-type: none"> • Translating verbal descriptions of work schedule and into a time sheet • Calculating total number of hours worked and gross payment • Optional mid-task switch to call manager to report number of hours worked 	17 points	8 minutes
Telephone Communication (Scott et al., 2011)	<ul style="list-style-type: none"> • Dialing three phone numbers • Leaving voice message with three pieces of information • Searching for phone numbers in provided phone book 	15 points	3 minutes

Table 3. WHO-HPQ Absenteeism and Presenteeism

	MS (<i>n</i> = 18)	HC (<i>n</i> = 20)	<i>t</i> *	<i>p</i>
Absenteeism	35.42 ± 13.43	18.21 ± 2.49	2.02	.04
Presenteeism	75.28 ± 8.33	80.59 ± 12.10	-1.07	ns

NOTE: Values are mean ± SD

Abbreviations: HC, healthy control group; MS, Multiple Sclerosis; ns, not significant; WHO-HPQ, World Health Organization Health and Performance Questionnaire.

* *t* value

Table 4. Neuropsychological Outcome Scores

	MS (<i>n</i> = 18)	HC (<i>n</i> = 20)	<i>t</i> *	<i>p</i>
Neuropsychological Test				
Oral SDMT	37.33 ± 7.56	53.57 ± 12.7	-2.34	.02
TMT A	51.20 ± 7.74	52.54 ± 7.53	-.76	ns
TMT B	40.82 ± 13.24	52.69 ± 8.37	-1.97	.03
PASAT 3"	37.50 ± 9.73	49.24 ± 8.75	-2.01	.03
PASAT 2"	32.58 ± 9.21	47.10 ± 10.83	-2.46	.02
WAIS-IV Digit Span	51.28 ± 4.78	54.43 ± 5.35	-.59	ns
CVLT-II Immediate Total	48.30 ± 3.56	49.01 ± 7.46	-.66	ns
CVLT-II Delayed Recall Total	50.15 ± 3.99	52.41 ± 2.50	-.39	ns

NOTE: Values are T score mean ± SD

Abbreviations: CVLT-II, California Verbal Learning Test; HC, healthy control group; MS, Multiple Sclerosis; ns, not significant; PASAT, Paced Serial Addition Test; SDMT, Symbol Digit Modalities Test; TMT A, Trail Making Test A; TMT B, Trail Making Test B; WAIS-IV, Wechsler Adult Intelligence Scale-IV.

* *t* value

Table 5. VMT Performance Variables: Descriptive Analysis

VMT Variable	MS (<i>n</i> = 18)	HC (<i>n</i> = 20)
VMT Overall Score	33.00 ± 11.53	48.05 ± 11.17
VMT Intrusion Errors	1.10 ± 0.85	0.65 ± 0.96
VMT Repetition Errors	0.65 ± 0.88	0.53 ± 0.87
VMT Omission Errors	2.30 ± 1.14	0.40 ± 0.75
VMT Sequencing Errors	0.35 ± 0.49	0.24 ± 0.44
VMT Total Errors	5.46 ± 1.57	1.15 ± 0.32
VMT Switch	0.59 ± 0.87	0.95 ± 1.15
VMT Switch & Attempts	4.41 ± 2.85	7.00 ± 4.33
VMT Total Changes	5.10 ± 2.90	7.43 ± 4.87
VMT Simultaneous	0.35 ± 0.79	2.24 ± 1.89
VMT Plan Time	17.88 ± 22.28	21.05 ± 20.90

NOTE: Values are raw score mean ± SD

Abbreviations: HC, healthy control group; MS, Multiple Sclerosis; VMT, Vocational Multitasking Test

Table 6. Correlational Analyses Between VMT and Neuropsychological Variables

MS				
	Overall	Sim.	Error	Changes
NP Variable				
PASAT-Total	.21	.32	.16	.49*
SDMT-Total	.62*	.04	.28	.05
CVLT-II Immed.	.15	.13	.30	.17
CVLT-II Delay.	.25	.40	.29	.21
Digit Span	.32	.19	.04	.38
TMT-A	.37	.09	.25	.29
TMT-B	.57*	.52*	.29	.11
HC				
	Overall	Sim.	Error	Changes
NP Variable				
PASAT-Total	.26	.26	.04	.25
SDMT-Total	.52*	.37	.16	.52*
CVLT-II Immed.	.27	.33	.20	.28
CVLT-II Delay.	.09	.02	.03	.19
Digit Span	.37	.40	.26	.30
TMT-A	.24	.28	.09	.05
TMT-B	.36	.14	.15	.18

NOTE: Values are r_s

Abbreviations: Changes, VMT Total Changes; CVLT-II Delay, California Verbal Learning Test Second Edition Delayed Free Recall; CVLT-II Immed, California Verbal Learning Test Second Edition Immediate Free Recall; Error, VMT Total Errors; HC, healthy control group; MS, Multiple Sclerosis; Overall, VMT Overall Score; PASAT, Paced Serial Addition Test; SDMT, Sim, VMT Simultaneous; Symbol Digit Modalities Test; TMT A, Trail Making Test A; TMT B, Trail Making Test B

* $p < .05$

Vita

Chelsea Morse

EDUCATION

Pre-Doctoral Internship July 2013-present	Emory University School of Medicine, Atlanta, GA Clinical Neuropsychology
Ph.D. 2014	Drexel University, Philadelphia, PA Doctor of Philosophy in Clinical Psychology (APA) Concentration: Clinical Neuropsychology
M.S. 2012	Drexel University, Philadelphia, PA Major: Clinical Psychology (APA accredited) Concentration: Clinical Neuropsychology
B.S. 2009	The Pennsylvania State University, State College, PA Major Field of Study: Biobehavioral Health Minor Field of Study: Psychology The Schreyer's Honors College: <i>Honors in Psychology</i>

AWARDS AND HONORS

- National Academy of Neuropsychology, Edith Kaplan Award, 2012
- National Academy of Neuropsychology, Student Poster Award, 2012
- National Academy of Neuropsychology, Student Research Award, 2012
- Drexel University, Travel Grant, 2012
- Drexel University, Travel Grant, 2010
- Drexel University, Provost Fellowship, 2009-2010

PUBLICATIONS

1. Morse, C.L., McKeever, J., Schultheis, M.T., & Leist, T. (2013). Multitasking in multiple sclerosis: Can it inform vocational functioning? *Archives of Physical Medicine and Rehabilitation*, 94(12), 2509-14.
2. Morse, C.L., Douglas, K., Mandel, S., & Swirsky-Sacchetti, T. (2013). Utility of the Rey-15 recognition trial to detect suspect effort in a forensic neuropsychological population. *The Clinical Neuropsychologist*, 27(8), 1395-1407.

TEACHING EXPERIENCE

Introduction to General Psychology
Abnormal Psychology
Physiological Psychology
Principles of Neuroscience

